SEMIARID PRECIPITATION FREQUENCY PROJECT

Update of *Technical Paper No. 40, Technical Paper No. 49* and *NOAA Atlas 2*

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Hydrometeorological Design Studies Center
Hydrology Laboratory

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DISCLAIMER

The data and information presented in this report should be considered as preliminary and are provided only to demonstrate current progress on the various technical tasks associated with this project. Values presented herein are NOT intended for any other use beyond the scope of this progress report. Anyone using any data or information presented in this report for any purpose other than for what it was intended does so at their own risk

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1. Introduction

The Hydrometeorological Design Studies Center (HDSC), Hydrology Laboratory, Office of Hydrologic Development, U.S. National Weather Service is updating its precipitation frequency estimates for the Semiarid Southwestern United States. Current precipitation frequency estimates for the Semiarid region are contained in *Technical Paper No. 40* "Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years" (Hershfield 1961), *Technical Paper No. 49* "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al 1964), *NOAA Atlas 2* "Precipitation-Frequency Atlas of the Western United States" (Miller et al 1973), "Short Duration Rainfall Frequency Relations for California" (Frederick and Miller, 1979) and "Short Duration Rainfall Relations for the Western United States" (Arkell and Richards, 1986). The new project includes collecting data and performing quality control, compiling and formatting datasets for analyses, selecting applicable frequency distributions and fitting techniques, analyzing data, mapping and preparing reports and other documentation.

The project will determine annual all-season precipitation frequencies for durations from 5 minutes to 60 days, for return periods from 2 to 1000 years. The project will review and process all available rainfall data for the Semiarid project area and use accepted statistical methods. In particular, the Semiarid Project is the pilot project in which decisions regarding the methods and format are being made that will affect subsequent projects. The project results will be published as Volumes of *NOAA Atlas 14* on the internet using web pages with the additional ability to download digital files.

The Semiarid Project will produce estimates for 4 states completely, Arizona, Nevada, New Mexico, and Utah, and southeastern California. Additional data from 7 bordering states and Mexico (Figure 1) are included for continuity across state borders. The core and border areas and regional groups for long duration (24-hour through 60-day) analyses are shown in Figure 1. Regional groups for short duration (60-minute through 12-hour) analyses are shown in Figure 2.

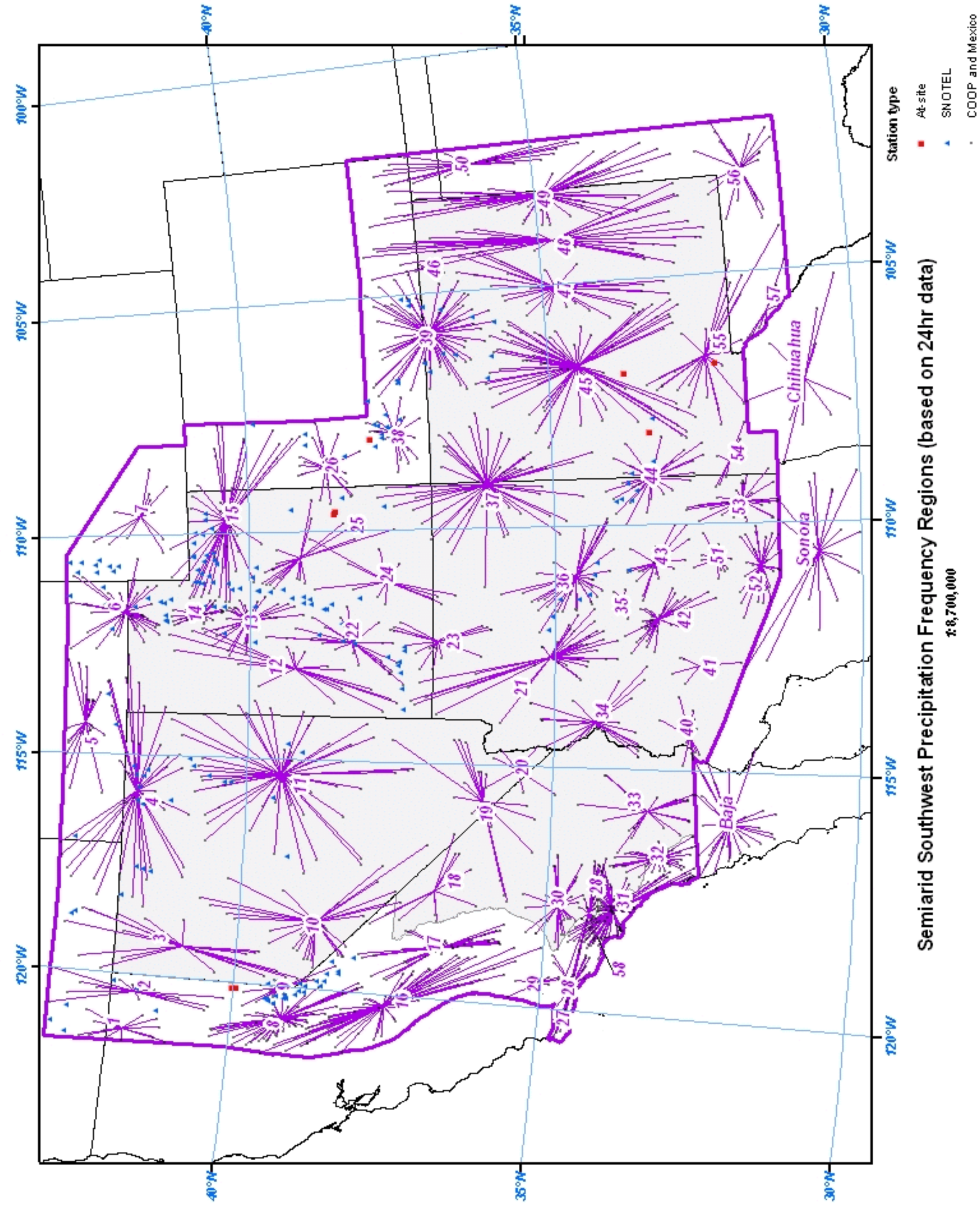

Figure 1. Semiarid Precipitation Frequency project area and new regional groups for 24-hour and longer duration values.

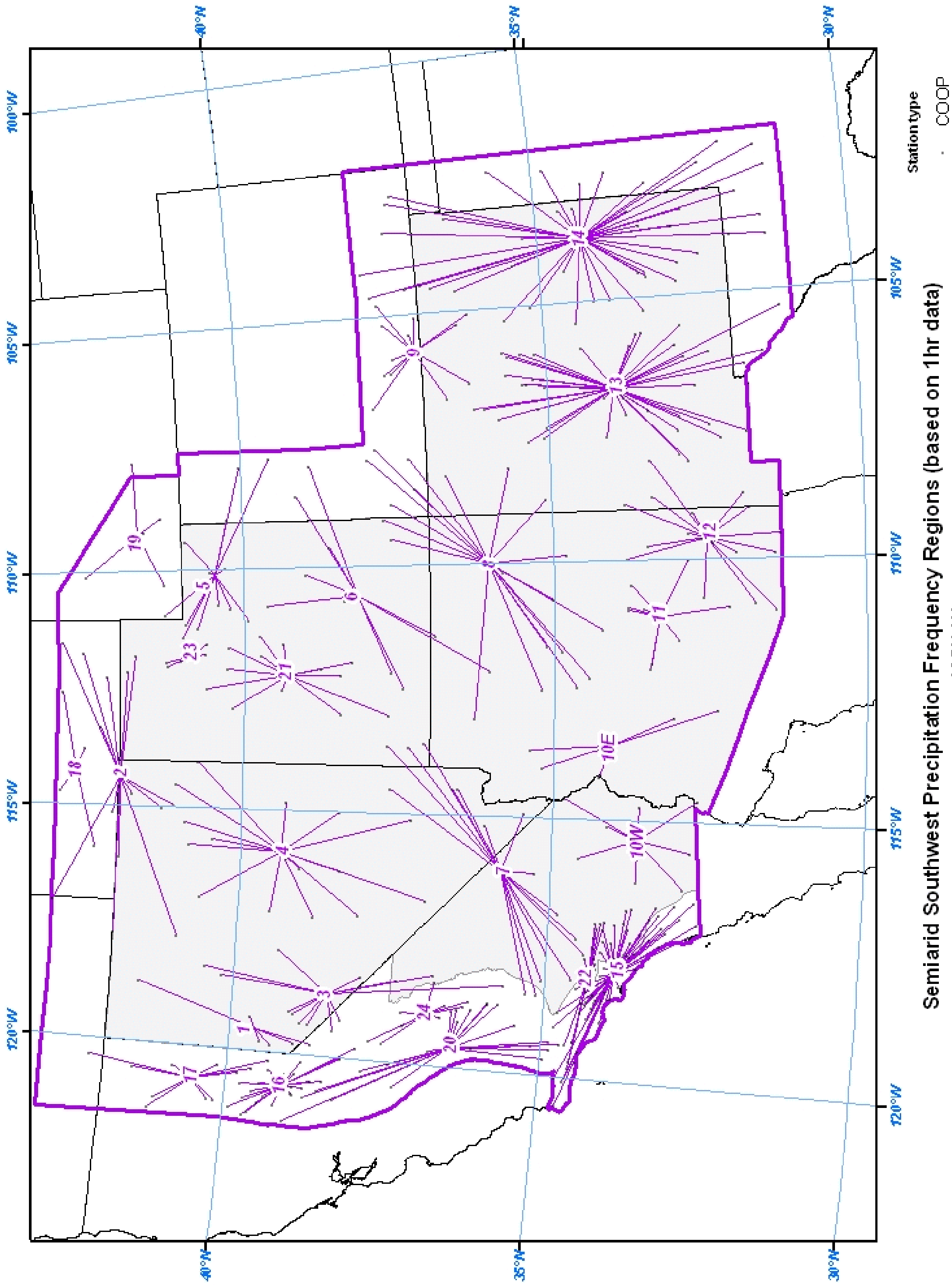

Figure 2. Semiarid Precipitation Frequency regional groups for 12-hour and shorter duration values.

2. Highlights

Newly added n-minute and hourly data in Riverside County, California were extensively quality controlled and final precipitation frequency estimates were critically reviewed. Additional information is provided in Section 4.1, Data Addition.

Software to compute multi-day duration return frequencies was refined to accommodate different numbers of stations and to insure internal consistency between 24-hour and 48-hour durations. Software was also modified to accommodate SNOTEL stations in a similar fashion. Software to calculate confidence limits for all durations and return frequencies was refined for all stations, particularly SNOTEL stations. Additional information is provided in Section 4.2, Software Updates.

Temporal distributions are complete. Documentation has been written. The temporal distribution analysis and statistical trend analysis results are appended at the end of this Progress Report for review. Additional information is provided in Section 4.3, Temporal Distributions and Statistical Trend Analysis.

On February 14th, 2003 the Spatial Climate Analysis Service (SCAS) at Oregon State University delivered the final mean annual maximum (a.k.a. "index flood") grids for the Semiarid Southwest to HDSC for all durations. Spatial artifacts were used to flag stations that required further inspection. Additional information is provided in Section 4.4, Spatial Interpolation.

The Precipitation Frequency Data Server (PFDS) is now operating at much faster speeds and is nearly ready for public release. Additional information is provided in Section 4.5, Precipitation Frequency Data Server.

Progress towards the development of depth-area-duration (D-A-D) reduction relationships for areas from 10 to 400 square miles continues. An additional area in Hawaii has been added to the project. Additional information is provided in Section 4.6, Depth Area Duration Project.

HDSC presented four papers/posters at the 83rd American Meteorological Society Annual Meeting in February of 2003. Preliminary Semiarid 100-year 60-minute and 100-year 24-hour spatially-interpolated maps and a comparison between current 100-year 24-hour point estimates and NOAA Atlas 2 were presented and well-received. Additional information is provided in Section 5.1, AMS Annual Meeting.

3. Status

3.1 Project Task List

The following checklist shows the components of each task and an estimate of the percent completed per task. Past status reports should also be referenced for additional information.

Semiarid project checklist [estimated percent complete]:

Data Collection, Formatting and Quality Control [100%]:
- Multi-day
- Daily
- Hourly
- 15-minute
- N-minute

Additional n-minute and hourly data that were added in Riverside County, CA were extensively quality controlled. The datasets are complete.

L-Moment Analysis/Frequency Distribution for 5 minute to 60 days and 2 to 1000 years [100%]:
- Multi-day
- Daily
- Hourly
- 15-minute
- N-minute

L-moments results in regions that were affected by the addition of new hourly data were critically reviewed. Multi-day precipitation frequency estimates were re-computed on all regions using refined software to prevent minor internal inconsistencies. All precipitation frequency estimates are complete.

Spatial Interpolation [95%]

- Create mean annual maximum (a.k.a. “Index flood”) grids with PRISM for each duration (1-hr, 2-hr, 3-hr, 12-hr, 24-hr, 48-hr, 4-day, 7-day, 10-day, 20-day, 30-day, 45-day, 60-day)
- Apply a precipitation frequency map derivation procedure, known as the cascade residual add-back (CRAB) procedure to create a total of 162 grids. The same procedure will be used to create 162 upper and 162 lower bound precipitation frequency grids. (See Section 4.6 Spatial Interpolation for more details.)
- Apply project-wide conversion factor to the 60-minute precipitation frequency grids to calculate the n-minute (5-, 10-, 15-, and 30-minute) grids

Final grids of spatially interpolated annual maxima means (a.k.a. “index flood”) for all durations were created and reviewed.

Peer Reviews [100%]

- Lead review of point precipitation frequency estimates
- Lead review of spatial interpolation grids

Data Trend Analysis [100%]

- Analyze linear trends in annual maxima and variance over time
- Analyze shift in means of annual maxima between two time periods (i.e., test the equality of 2 population distribution means)

The trend and shift analyses of 1-day annual maximum series are complete. Documentation has been written.

Temporal Distributions of Extreme Rainfall [100%]

- Assemble hourly data by quartile of greatest precipitation amount and convert to cumulative rainfall amounts for each region
- Sort, average, and plot time distribution of hourly maximum events for different climatological regions and seasons

Temporal distributions are complete. Documentation has been written.

Deliverables [60%]

- Prepare data for web delivery
- Prepare documentation for web delivery
- Write hard copy of Final Report
- Publish hard copy of Final Report

Spatial data has been prepared and processes to produce final maps are in place.

Spatial Relations (Depth-Area-Duration Project) [67%]

- Obtain hourly data from dense-area reporting networks
- QC and format data from dense networks
- Compute maximum and average annual areal depth for each duration from stations for each network
- Compute ratio of maximum to average depth for all durations and networks and plot
- Prepare curves of best fit (depth-area curves) for each duration and network
- Combine all stations from all project areas to compute the ratio of maximum to average depth for all durations and networks and plot
- Examine differences in individual D-A-D curve plots for durations and different areas compared to those for combined area data plots

The D-A-D project is 2/3 completed. All areas to be used and tested in the D-A-D curve development have been selected and quality controlled. Software development to process the data and ultimately generate the D-A-D curves is 60% completed.

4. Progress in this Reporting Period

4.1 Data Addition

The additional data that was added to the n-minute and hourly datasets in Riverside County, California was extensively quality controlled. The data of 8 existing stations were supplemented and 22 new stations were added to hourly regions 10W and 15 (see Figure 2). Final 100-year 60-minute estimates changed between -10 to +26%, with most changes between ±3% (Table 1). Changes in final 100-year 24-hour estimates of affected daily regions 31, 32 and 33 were mostly between ±2% (Table 2).

Table 1. Impact of additional Riverside data to hourly regions.

hourly region	# hourly stns	change in 100yr 60min
10W	16 (6 new Riverside stns)	decrease <3%
15	81 (15 new Riverside stns) (4 replaced stns)	increase <3%; replaced stns varied btwn -10% and +26%

Table 2. Impact of additional Riverside data to daily regions.

daily region	# daily stns	# hourly stns	change in 100yr 24hr
31	80	52 (10 new Riverside stns)	decrease <1%
32	31	23 (10 new Riverside stns) (4 replaced stns)	increase <1%; replaced stns increase <11%
33	17	9 (2 new Riverside stns)	decrease <2%

4.2 Software Updates

Nine minor inconsistencies between daily and multi-day results were observed in precipitation frequency estimates. The inconsistencies typically occurred between 24-hour and 48-hour durations (i.e., the 24-hour estimate was greater than the 48-hour estimate). 24-hour estimates are calculated from a combined dataset of hourly stations and daily stations. Multi-day durations are calculated from daily stations only. Therefore, it was necessary to modify the multi-day internal consistency software to accommodate the different number of stations between 24-hour and 48-hour. This modification eliminated all observed inconsistencies.

It was also necessary to similarly modify existing internal consistency software specific to SNOTEL stations. SNOwpack TELemetry (SNOTEL) daily stations are included in the dataset to increase the spatial density of stations particularly at higher elevations. They are not used in the calculation of regional statistical parameters because their data is insufficient to calculate higher order l-moment statistics, and therefore, their precipitation frequency estimates are calculated using the regional frequency distribution parameters of the regions in which they reside. To achieve this separate software was written. This SNOTEL-specific software was modified to accommodate the different number of stations between 24-hour and 48-hour in a manner similar to the multi-day internal consistency software.

Software to calculate confidence limits was refined for all durations and frequencies for all stations, particularly SNOTEL stations. An internal consistency check was built in to the software.

4.3 Temporal Distributions and Statistical Trend Analysis

Temporal distributions for the 6-hour duration were completed for each of the four quartiles. Single plots combining all four quartiles into a single distribution were completed for the 6-hour, 12-hour, 24-hour and 4-day durations. Detailed documentation was written describing the temporal distributions and methodology.

The final results and documentation for the Temporal Distribution Analysis (Appendix A) and Statistical Trend Analysis of the annual maxima time series (Appendix B) are included for review. Timely comments regarding these draft documents are welcome and encouraged. There will not be a subsequent peer review of the final documentation due to time constraints.

4.4 Spatial Interpolation

On February 14th, 2003 the Spatial Climate Analysis Service (SCAS) at Oregon State University delivered the final mean annual maxima (a.k.a. “index flood”) grids for the Semiarid Southwest to HDSC for all durations (60-minutes through 60-day). This major milestone allowed HDSC to fully test, optimize and run the Cascade, Residual Add-back (CRAB) procedure. The CRAB procedure derives the precipitation frequency grids from the “index flood” grids and frequency distribution parameters. In fact, for the first time, we had the opportunity to see the final Semiarid Southwest precipitation frequency grids for all return frequencies and durations. Having the entire matrix of grids (Table 3) allowed for the evaluation and identification of very minor internal consistency issues (e.g., 100-year 2-hour > 100-year 3-hour). (See Section 4.2 Software Updates for more information.)

Upon examination of the Semiarid precipitation frequency grids, spatial-interpolation artifacts were used to flag stations that required closer inspection. Two particular spatial-interpolation artifacts (i.e., bulls-eyes in the contour lines) were observed. One of the artifacts was the result of a bad observation value at Beaverhead RS, NM which was corrected. A 1-day value of 4.45" on 9/29/1941 was actually a 3-day accumulation. The other artifact occurred around Bosque Del Apache, NM. Bosque Del Apache has sufficiently unique characteristics and met all of our criteria to require an “at-site” analysis. The station observed several significant storms in its 102-year record. After intense evaluation, it was determined the Bosque Del Apache and its surrounding areas are meteorologically prone to extreme events and thus justified the creation of a new region (region 59). To maintain the valuable storm information, Bosque Del Apache was kept “at-site” while eight other surrounding stations composed region 59. Region 59 is located at the periphery of daily regions 45 and 55 (see Figure 1).

In addition to the derivation of mean precipitation frequency grids, we also began the derivation of upper and lower confidence limit grids and the preparation of the final maps.

Table 3. List of all map/grid deliverables.

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr	1000-yr
5-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
10-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
15-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
30-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
60-min	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
120-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
3-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
6-hr	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
12-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
24-hr	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
48-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
4-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
7-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
10-day	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
20-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
30-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
45-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
60-day	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*

G = ArcInfo ASCII grid
S = ESRI shapefile of isohyets
SM = State-specific printable cartographic map (PDF format) (emphasized in **bold**)
SM* = State-specific printable cartographic map (PDF format) as time permits

4.5 Precipitation Frequency Data Server (PFDS)

Last quarter the available disk space for the PFDS computer server was increased to 30 gigabytes, but the access speed to the expanded disk was hindered by a slow network connection. This quarter the slow connection was resolved by moving the PFDS computer server to a faster internal network. The PFDS is now operating at much faster speeds and is ready for public release pending the incorporation of final data and any last-minute modifications.

4.6 Spatial Relations (Depth-Area-Duration Project)

Progress continues in the development of geographically-fixed depth-area-duration (D-A-D) reduction relationships for area sizes of 10 to 400 square miles. The second phase of the programming to relate spatial relationships in precipitation data used in the development of the D-A-D curves is nearly complete and will be tested in April 2003 on two areas.

The purpose of the programming is to generate statistics that measure the variability in the annual maximum for a given duration in a given area or basin. Means and standard deviations among groups of five stations, normalized to the distance between stations, are computed. Mean areal depths (using annual maximum precipitation) in a basin are generated, in order to ultimately compute the ratios of mean annual maximum amounts at stations to the mean areal annual maximum. To quality check the software, data from an earlier study (NOAA Technical Report NWS 24, using this D-A-D development approach) is being duplicated to verify that the same statistics are being generated using our software development. This is the last major software development for the project.

An additional area in Hawaii has been added to the project. A total of 13 different geographic areas throughout the United States have been quality controlled and will be used in the project. The set of curves developed for each area will be tested for differences to determine if a single set of D-A-D curves is applicable to the entire U.S. Otherwise, separate curves for different regions of the country will be developed.

5. Issues

5.1 AMS Annual Meeting

HDSC presented four papers/posters at the 83rd American Meteorological Society Annual Meeting in February of 2003. In *Updating NOAA/NWS Rainfall Frequency Atlases*, we provided an overview of our approach; in *Updated Precipitation Frequencies for the Semiarid Southwest United States*, we presented preliminary 100-year 60-minute and 100-year 24-hour spatially interpolated maps and a comparison between current 100-year 24-hour point estimates and NOAA Atlas 2; in *Updated Precipitation Frequencies for the Ohio River Basin and Surrounding States*, we presented preliminary 100-year 60-minute and 100-year 24-hour point estimates from the Ohio project and a comparison between current 100-year 24-hour point estimates and Technical Paper 40; and in *NOAA/NWS Precipitation Frequency Data Server*, we presented the PFDS in detail. The papers were well received and the posters generated significant interest and anticipation of final publication.

6. Projected Schedule.

The following list provides a tentative schedule with completion dates. Brief descriptions of tasks being worked on next quarter are also included in this section.

Data Collection and Quality Control [complete]
L-Moment Analysis/Frequency Distribution [complete]
Temporal Distributions of Extreme Rainfall [complete]
Peer review of point estimates [complete]
Trend Analysis [complete]
Spatial Interpolation [April 2003]
Precipitation Frequency Maps [April 2003]
Final Report [June 2003]
Web Publication [June 2003]
Spatial Relations (Depth Area Duration Studies) [May 2003]

6.1 L-Moment Analysis/Frequency Distribution.

Final confidence limits associated with each precipitation frequency estimate will be computed and adjusted for internal consistency in the next quarter. New partial duration series will be generated to calculate the final conversion factors with annual maximum series.

6.2 Spatial Interpolation

Final map and shapefile deliverables will be produced during the next quarter.

6.3 Documentation

Final documentation will be written and the final version of the PFDS will be constructed during the next quarter.

6.4 Spatial Relations (Depth-Area-Duration Project)

Software for the D-A-D computations will be completed in the next quarter and the computations will be performed for 13 areas, and the resulting curves will be tested for differences to determine if a single set of D-A-D curves is applicable to the entire U.S. or whether curves vary by region.

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Appendix A

Temporal Distributions of Heavy Rainfall in the Semiarid Southwest United States

Introduction. Temporal distributions of heavy precipitation are provided for use with precipitation frequency estimates in the Semiarid Southwest Project area for 6-, 12-, 24- and 96-hour durations. The temporal distributions are expressed in probabilistic terms as cumulative percentages of precipitation and duration at various percentiles. The starting time of precipitation accumulation was defined in the same fashion as it was for precipitation frequency estimates for consistency. Therefore the results are biased towards the beginning of the distributions.

The study area was divided into two sub-regions based on the seasonality of observed heavy precipitation events. Figure 1 shows the areal divisions for the temporal distribution regions.

Temporal distributions for each duration are presented in Figures 2 and 3. The data were also subdivided into quartiles based where in the distribution the most precipitation occurred in order to provide more specific information on the varying distributions that were observed. Figures 4 through 11 depict temporal distributions for each quartile for the four durations. Table 1 lists the number and proportion of cases in each quartile for each duration and region.

Methodology. This study largely follows the methodology used by the Illinois State Water Survey (Huff, 1990) except in the definition of the precipitation accumulation. This study computed rainfall accumulations for specific (6-, 12-, 24- and 96-hour) time periods as opposed to for “events” or “storms” in order to be consistent with the way time is defined in the associated precipitation frequency studies. As a result, the accumulations may contain parts of, one, or more than one precipitation event. Accumulation computations were made moving from earlier to later in time resulting in an expected bias towards front loaded distributions.

The General and Convective Precipitation Areas (Figure 1) were established using factors set forth in previous work (Gifford *et al.*, 1967; NOAA, 1989), including the seasonality of maximum precipitation and event types. Maximum events in the General Precipitation Area were dominated by cool season precipitation while maximum events in the Convective Precipitation Area occurred in the warm season.

For every rainfall observing station in the study area that recorded rainfall at least once an hour, the three largest precipitation accumulations were selected for each month in the entire period of record and for each of the four durations. A minimum threshold of 0.50 inch was established to make sure only heavier precipitation cases were being captured.

Each of the accumulations was converted into a ratio of the cumulative hourly precipitation to the total precipitation for that duration, and a ratio of the cumulative time to the total time. Thus, the last value of the summation ratios always had a value of 100%. Within the General Area, and separately within the Convective Precipitation Area, the data were combined, cumulative deciles of precipitation were computed at each time step, and then results were plotted to provide the graphs presented in Figures 2 and 3. The data were also separated into categories by the quartile in which the most precipitation occurred and the procedure was repeated for each quartile category to produce the graphs shown in Figures 4 through 11.

Interpreting the Results. Figures 2 and 3 present cumulative probability plots of temporal distributions for the 6-, 12-, 24- and 96-hour durations for the General and the Convective Precipitation Areas. Figures 4 through 11 present the same information but for categories based on the quartile of most precipitation. The x-axis is the cumulative percentage of the time period. The y-axis is the cumulative percentage of total precipitation.

The data on the graph represent the average of many events illustrating the cumulative probability of occurrence at 10% increments. For example, the 10% line represents the distribution in which the most precipitation is concentrated at the beginning of the time period. At the other end of the spectrum, only 10% of cases are likely to have a temporal distribution falling to the right or below the 90% line. The 50% line represents the median temporal distribution on each graph.

First-quartile graphs consist of cases where the greatest percentage of the total rain fell during the first quarter of the time period. i.e., the first 1.5 hours of a 6-hour period, the first 3 hours of a 12-hour period, etc. The second, third and fourth quartile plots, similarly are for cases where the most precipitation fell in the second, third or fourth quartile of the time period.

The cases of the Convective Precipitation Area had steeper gradients than the cases of the General Precipitation Area, particularly for the first-quartile category. As presented in Table 1, about 50 percent of all cases fell in the first quartile, due in part to how the accumulation period was defined. More specifically, first quartile cases ranged from 60 percent of all cases at the 96-hour duration in the Convective Precipitation Area to 41 percent at the 6-hour duration in the General Precipitation Area.

The following is an example of how to interpret the results using Figure 8A. Of the 4,176 cases in the General Precipitation Area, 1,952 of them were first-quartile events:

$ In 10 percent of these cases, 50% of the total rainfall (y-axis) fell in the first 1.2 hours of event time (5% on the x-axis). By the 9th hour (37.5% on the x-axis), the total amount of precipitation (100% on the y-axis) had fallen.

$ A median case of this type will drop half of it=s total rain (50% on the y-axis) in 4.2 hours (17.5% on the x-axis).

$ In 90 percent of these events, 50% of the total precipitation fell by the 9th hour.

Summary and General Findings. The results presented here can be used for determining temporal distributions of heavy rainfall of particular durations and amounts and at particular levels of probability. The results are designed for use with precipitation frequency estimates and therefore may not apply to the temporal distributions of single storms or single precipitation “events”. A majority of the cases analyzed were first-quartile cases regardless of precipitation area or duration (Table 1). Fewer and fewer cases fell into each of the subsequent quartile categories with the fourth quartile containing the fewest number of cases. Overall, the Convective Precipitation Area distributions showed a steeper gradient and therefore depicted more initially intense precipitation than the General Precipitation Area distributions regardless of duration.

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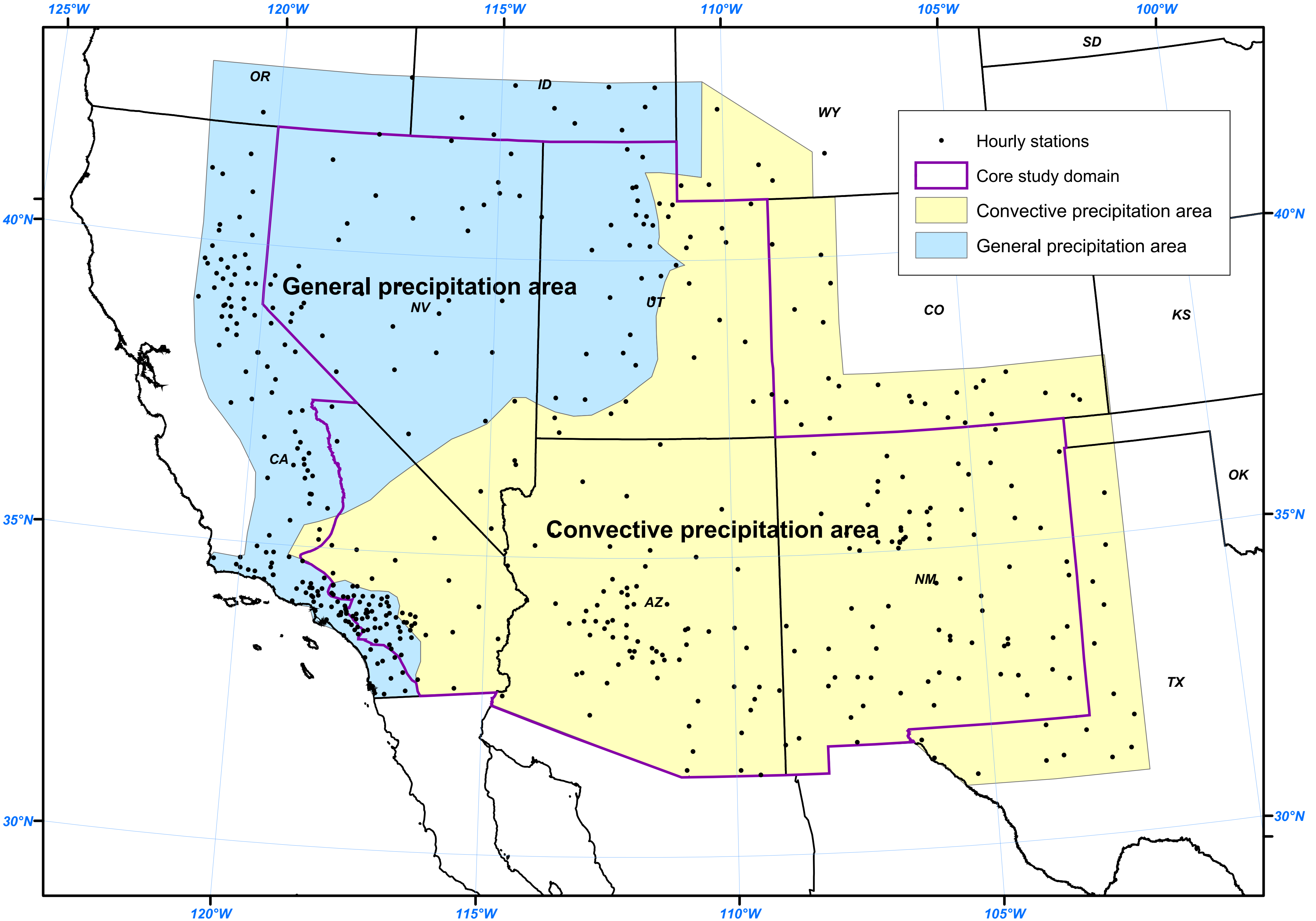

Figure 1. Semiarid Southwest Precipitation Frequency Temporal Distribution Precipitation Regions

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Projection: Lambert Conformal Conic Datum: NAD83 Standard parallels: 38˚N & 45˚N Central meridian: 112˚W Filename: new_SA_regions.mxd Date: 2/4/2003 Initials: TWP

FIGURE 2
SEMIARID - GENERAL PRECIPITATION AREA
TIME DISTRIBUTION: ALL CASES

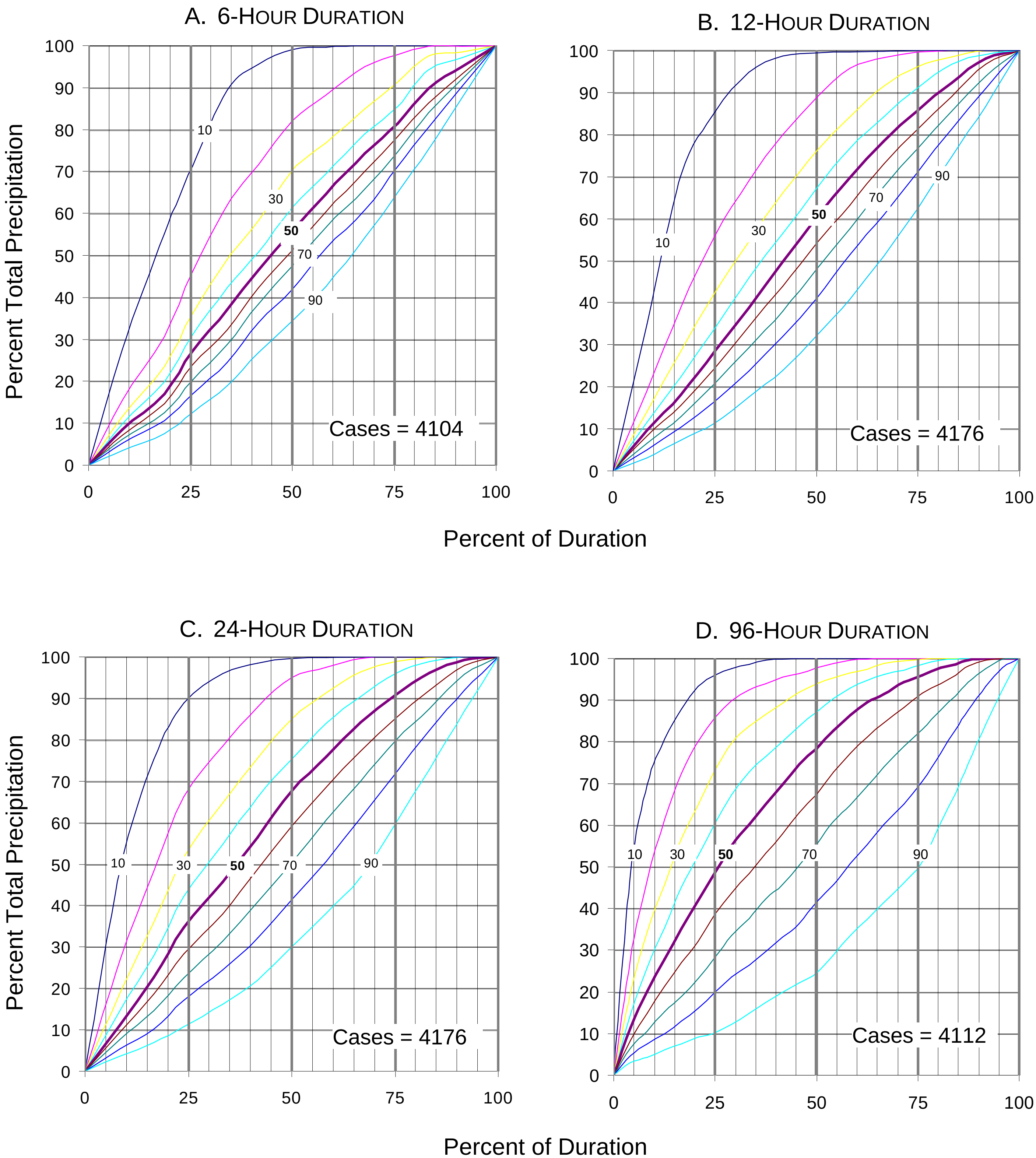


FIGURE 3
SEMIARID - CONVECTIVE PRECIPITATION AREA
TIME DISTRIBUTION: ALL CASES

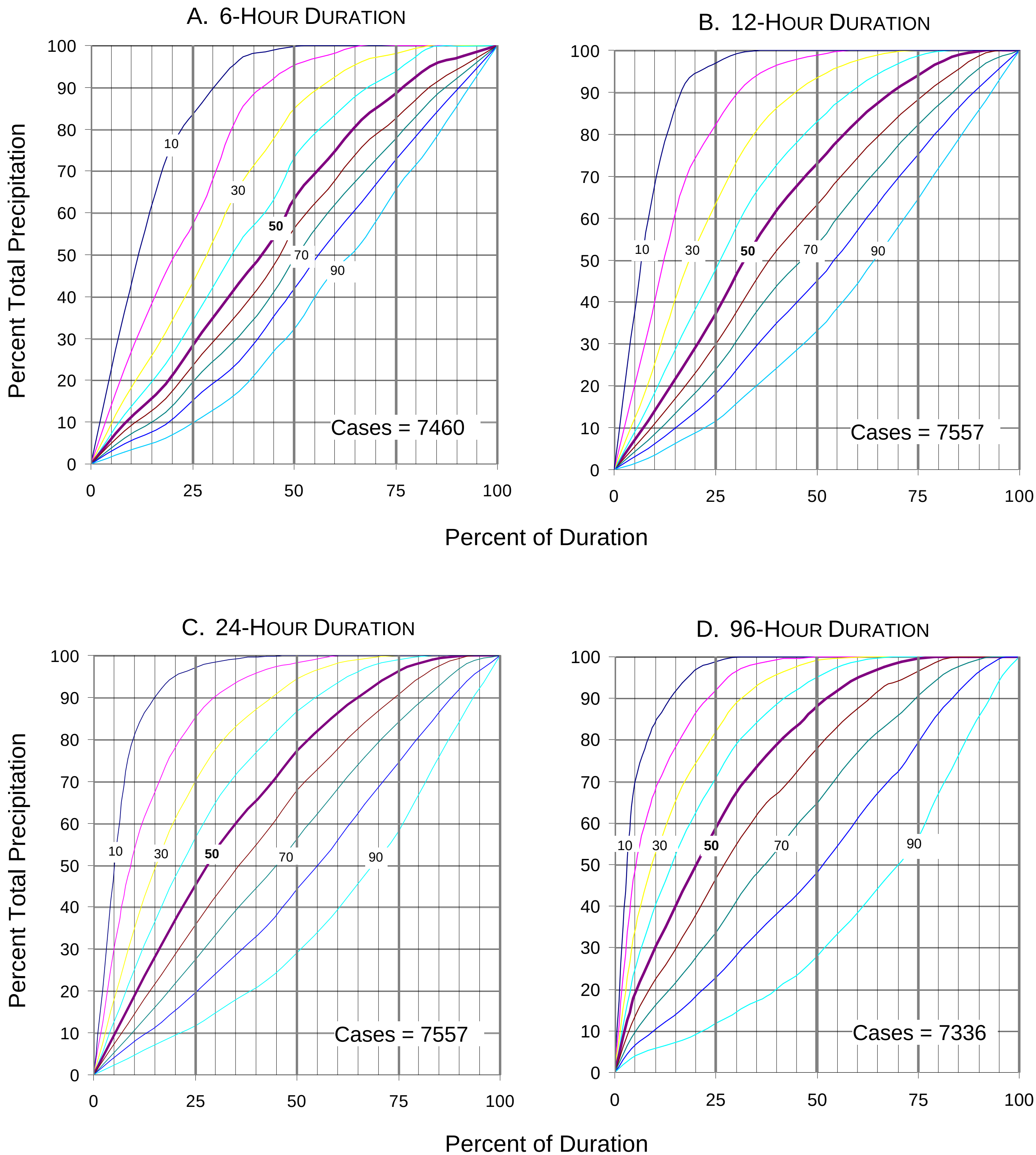


Figure 4
Semiarid - General Precipitation Area - 4104 Cases
Time Distribution: 6-Hour Duration

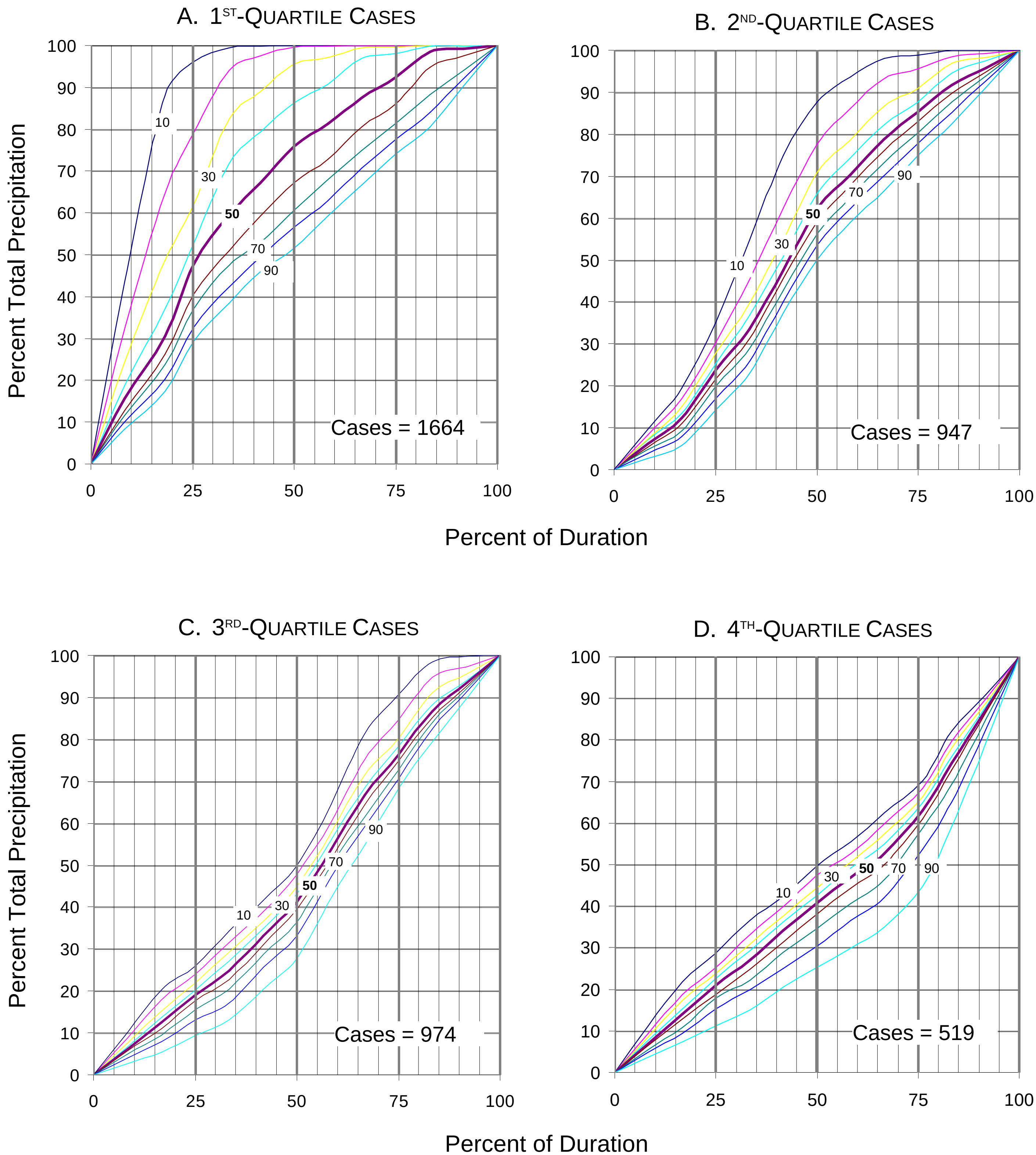


FIGURE 5
SEMIARID - CONVECTIVE PRECIPITATION AREA - 7757 CASES
TIME DISTRIBUTION: 6-HOUR DURATION

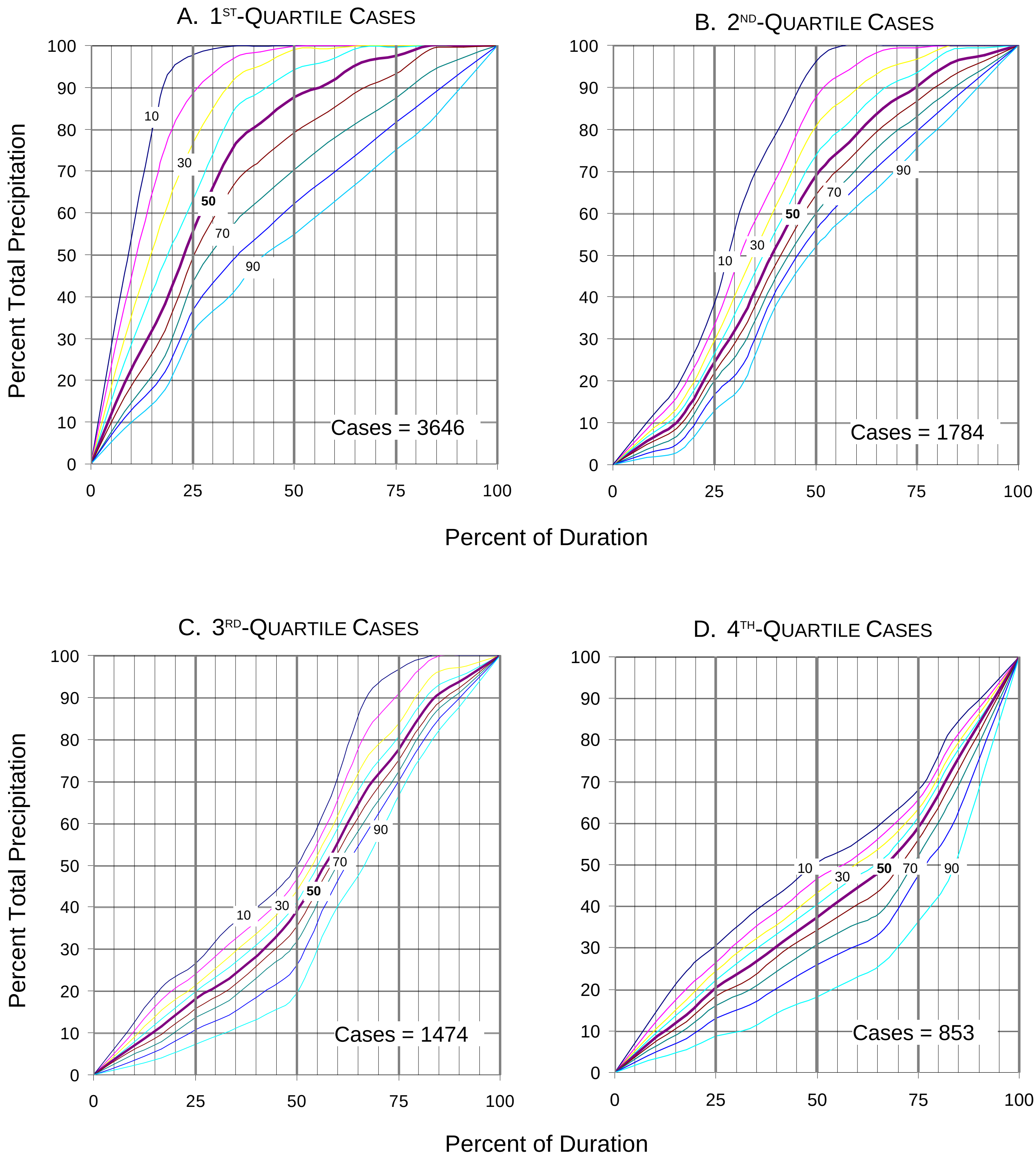


Figure 6
Semiarid - General Precipitation Area - 4176 Cases
Time Distribution: 12-Hour Duration

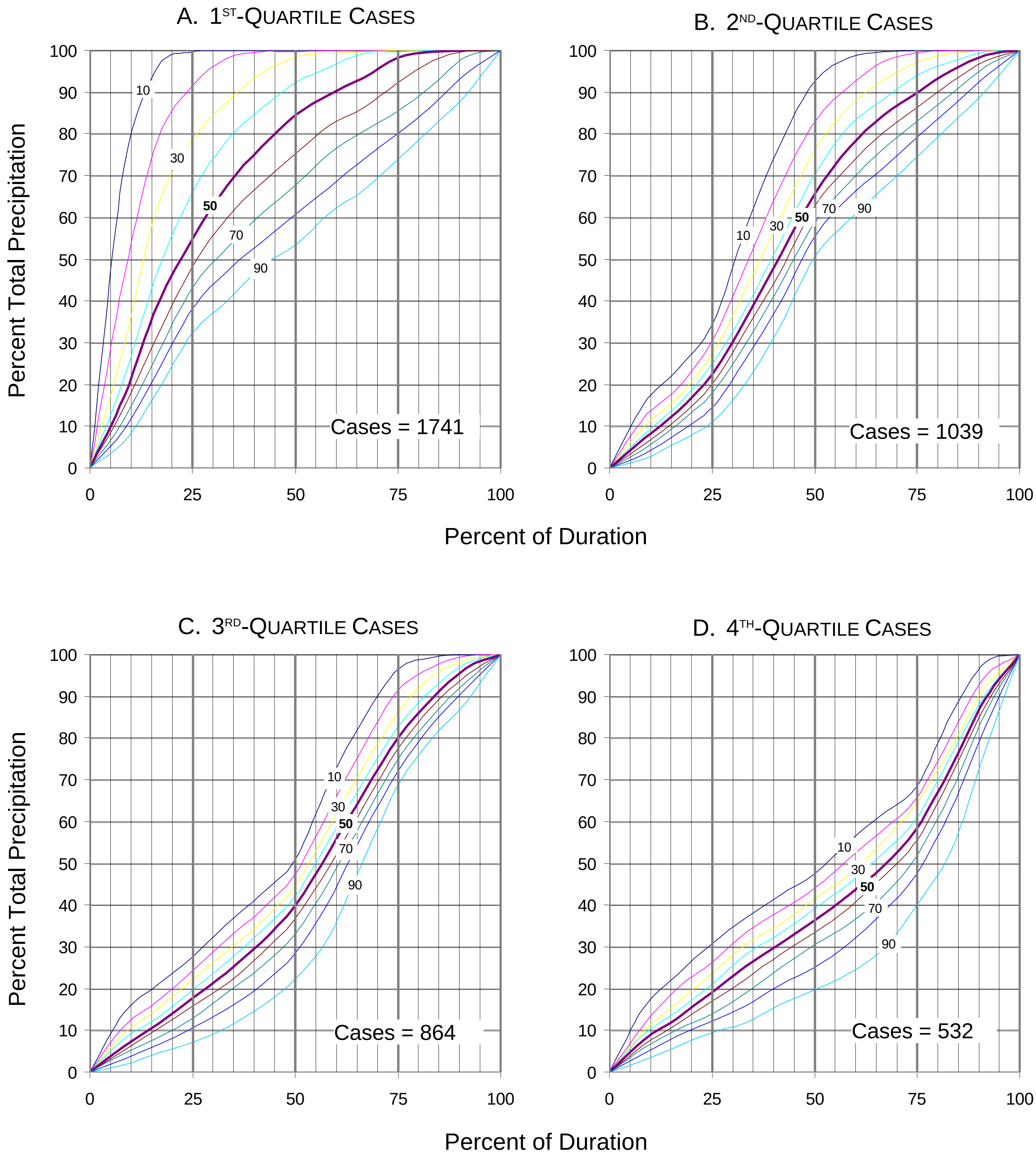


FIGURE 7

SEMIARID - CONVECTIVE PRECIPITATION AREA - 7557 CASES

TIME DISTRIBUTION: 12-HOUR DURATION

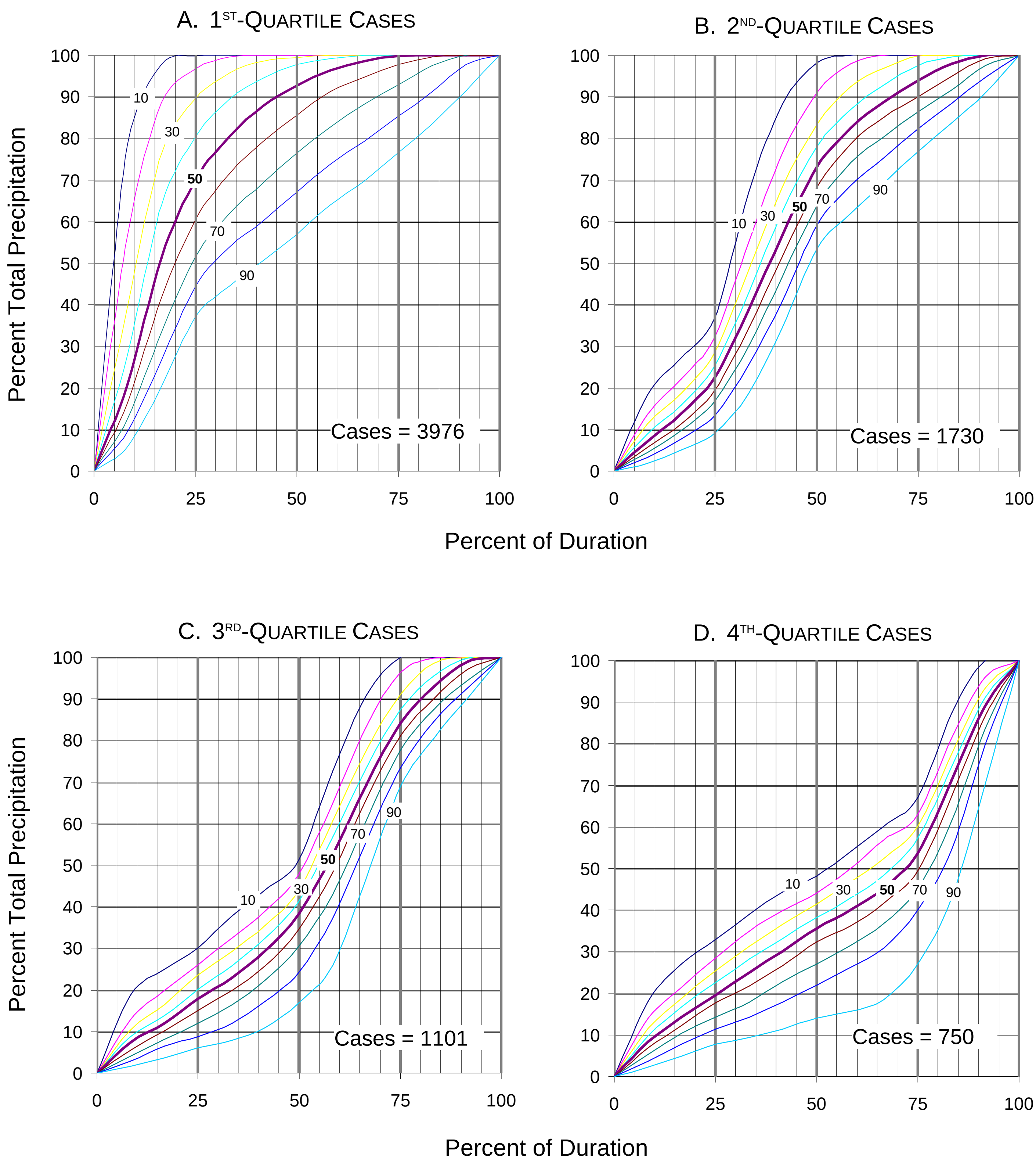


FIGURE 8
SEMIARID - GENERAL PRECIPITATION AREA - 4176 CASES
TIME DISTRIBUTION: 24-HOUR DURATION

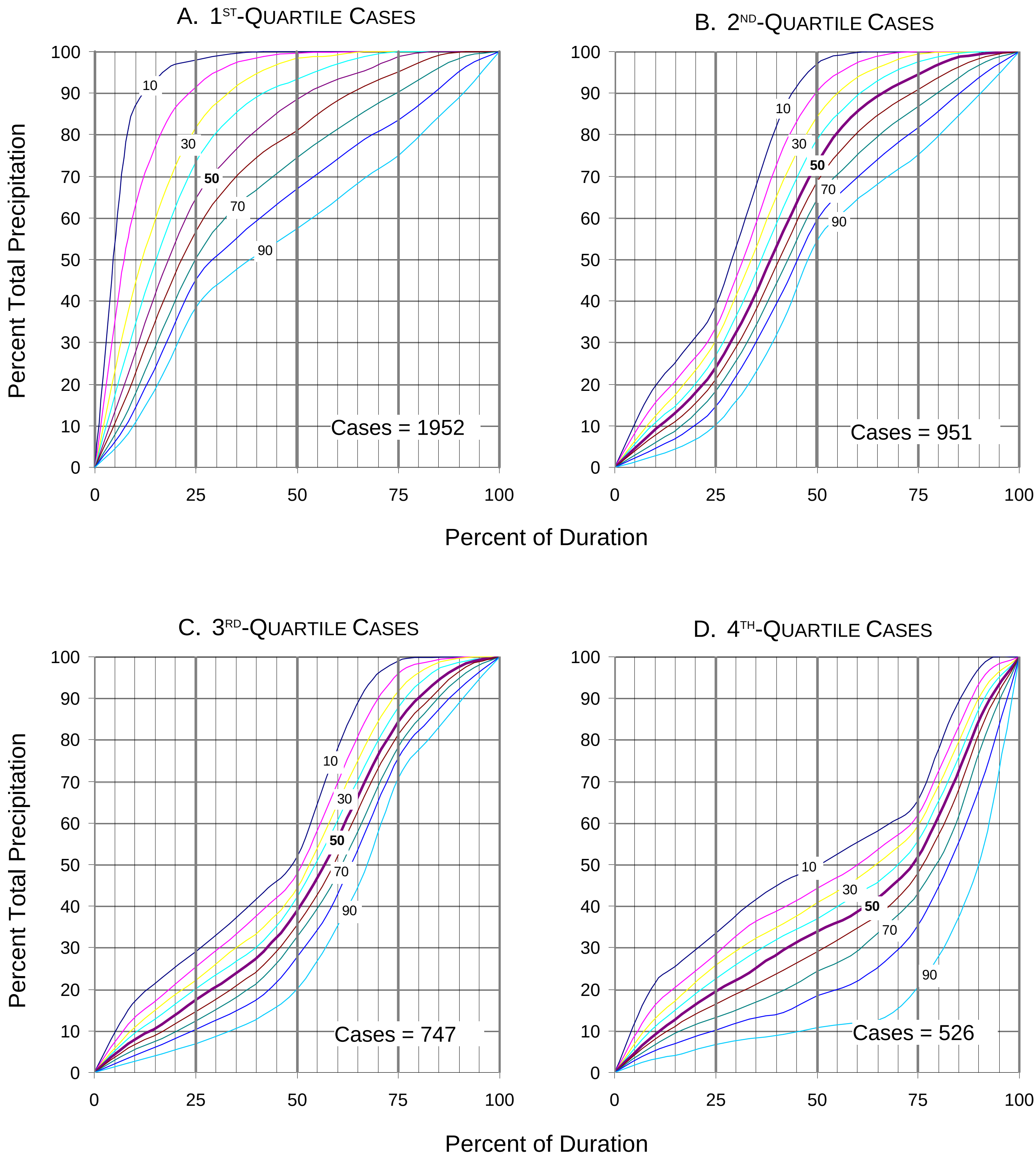


FIGURE 9

SEMIARID - CONVECTIVE PRECIPITATION AREA - 7557 CASES

TIME DISTRIBUTION: 24-HOUR DURATION

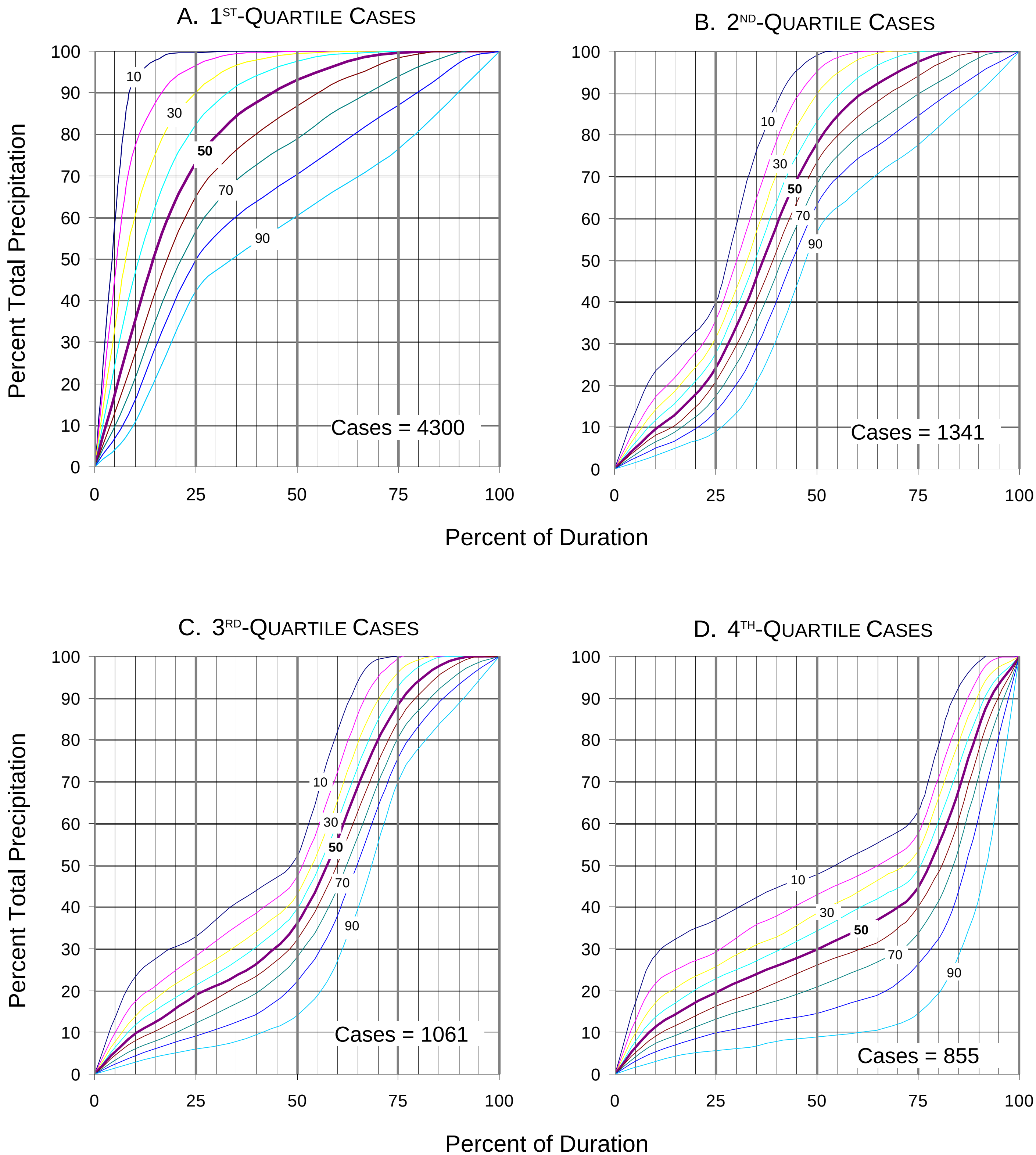


FIGURE 10
SEMIARID - GENERAL PRECIPITATION AREA - 4112 CASES
TIME DISTRIBUTION: 96-HOUR DURATION

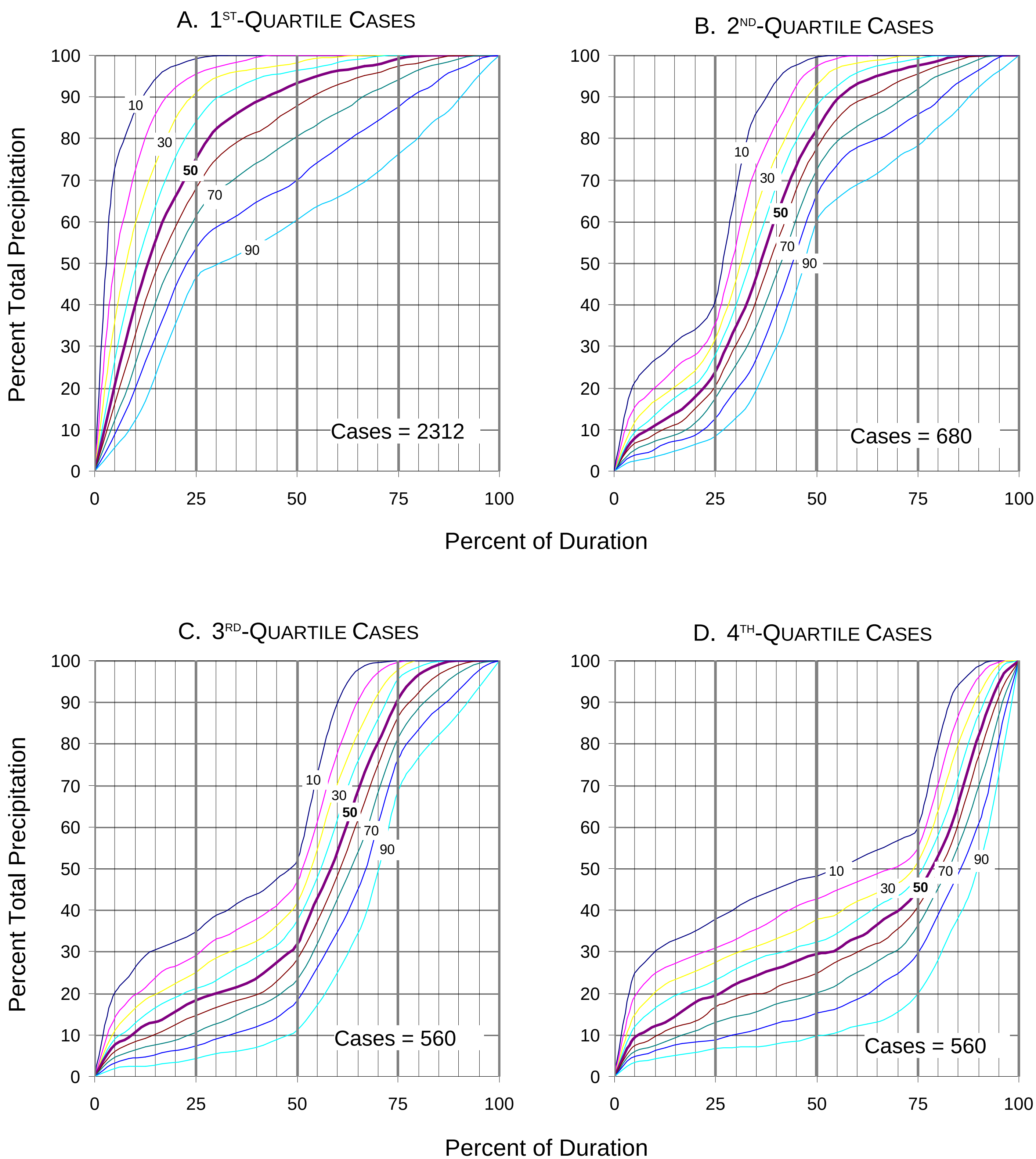
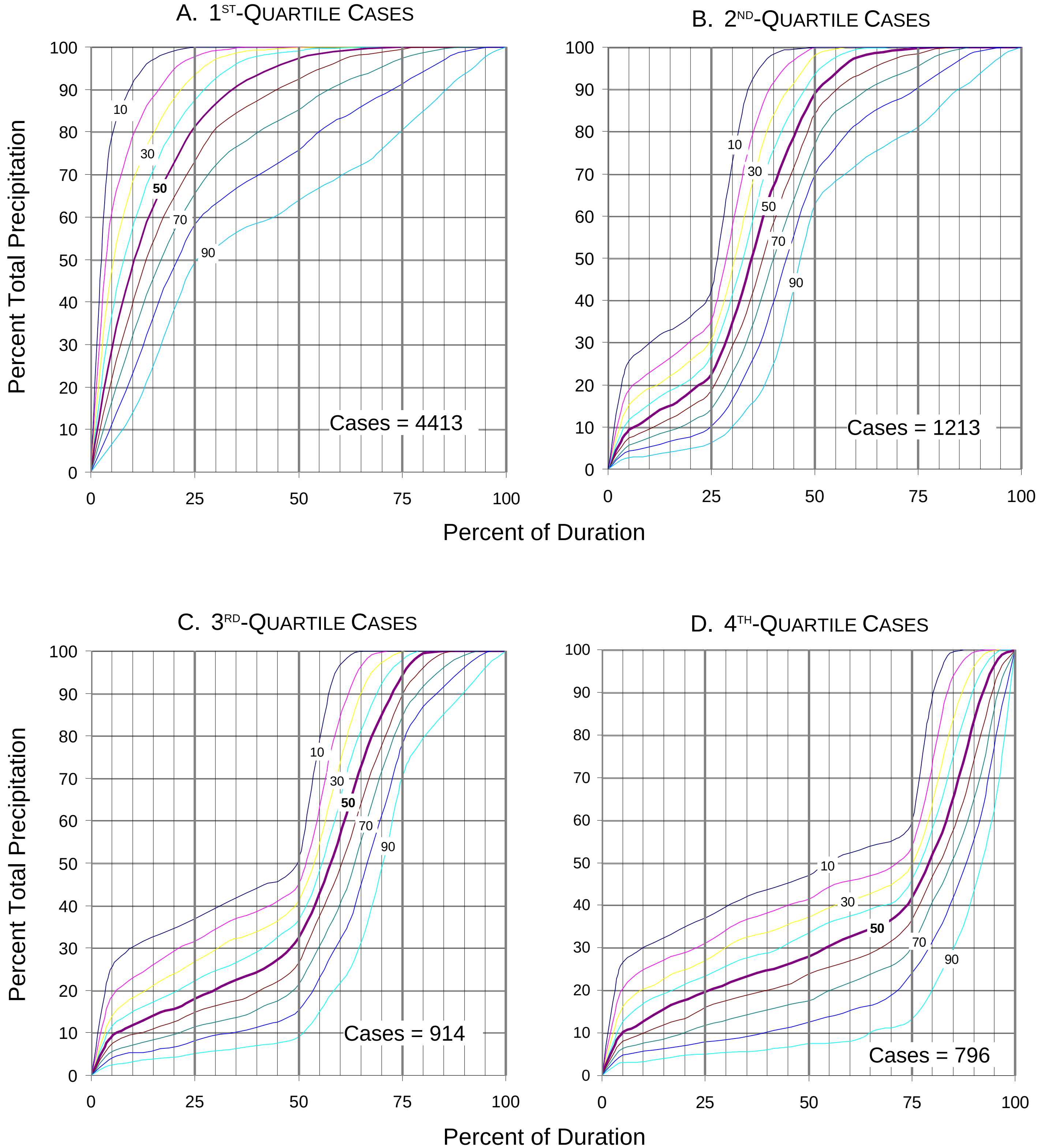


FIGURE 11
SEMIARID - CONVECTIVE PRECIPITATION AREA - 7336 CASES
TIME DISTRIBUTION: 96-HOUR DURATION



Convective Precipitation Area Number of Cases					
	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile	total number of cases
6-hr	3506 (47%)	1716 (23%)	1417 (19%)	821(11%)	7460
12-hr	3976 (53%)	1730 (23%)	1101 (15%)	750 (10%)	7557
24-hr	4300 (57%)	1341 (18%)	1061 (14%)	855 (11%)	7557
96-hr	4413 (60%)	1213 (17%)	914 (12%)	796 (11%)	7336

General Precipitation Area Number of Cases					
	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile	total number of cases
6-hr	1664 (41%)	947 (23%)	974 (24%)	519 (13%)	4104
12-hr	1741 (42%)	1039 (25%)	864 (21%)	532 (13%)	4176
24-hr	1952 (47%)	951 (23%)	747 (18%)	526 (13%)	4176
96-hr	2312 (56%)	680 (16%)	560 (14%)	560 (14%)	4112

Table 1.

Appendix B
Semiarid Time Series Statistical Trend Results

Introduction

Precipitation frequency studies make the implicit assumption that the past is prologue for the future, that climate is constant. It is assumed that the data used in such a project are suitable for analysis in this regard (i.e., are not significantly influenced by any climate change) and that they are identically and independently distributed. Tests for randomness, linear trends and shifts in mean were conducted on the 1-day annual maximum time series to verify the suitability of the data for the NOAA Atlas 14 Semiarid Southwestern United States Precipitation Frequency Project. The results of each test are provided and two specific examples of stations with linear trends and shift are presented here. It is concluded that while there are some instances of linear trends and shifts in mean in the data, it can be assumed that long-term effects of climate change are negligible for the precipitation frequency analyses in NOAA Atlas 14 and that the entire period of record can be used in the project.

Randomness Test

To successfully apply the L-moment analysis, data must be independent (or random). Each 1-day annual maximum series was tested for randomness using the non-parametric Runs statistical test (*Statistics of Business and Economics*, 1988, p679). A series must have at least 30 years of data to get a meaningful conclusion. Of 1449 stations, 82.6% had a sufficient period of record. Of those 1197 eligible stations, **11.9%** failed the randomness test at the 90% confidence level. In other words, almost 90% of the tested data passed the randomness test. Therefore, for the Semiarid Project area, the data may be considered random.

Linear Trend Tests

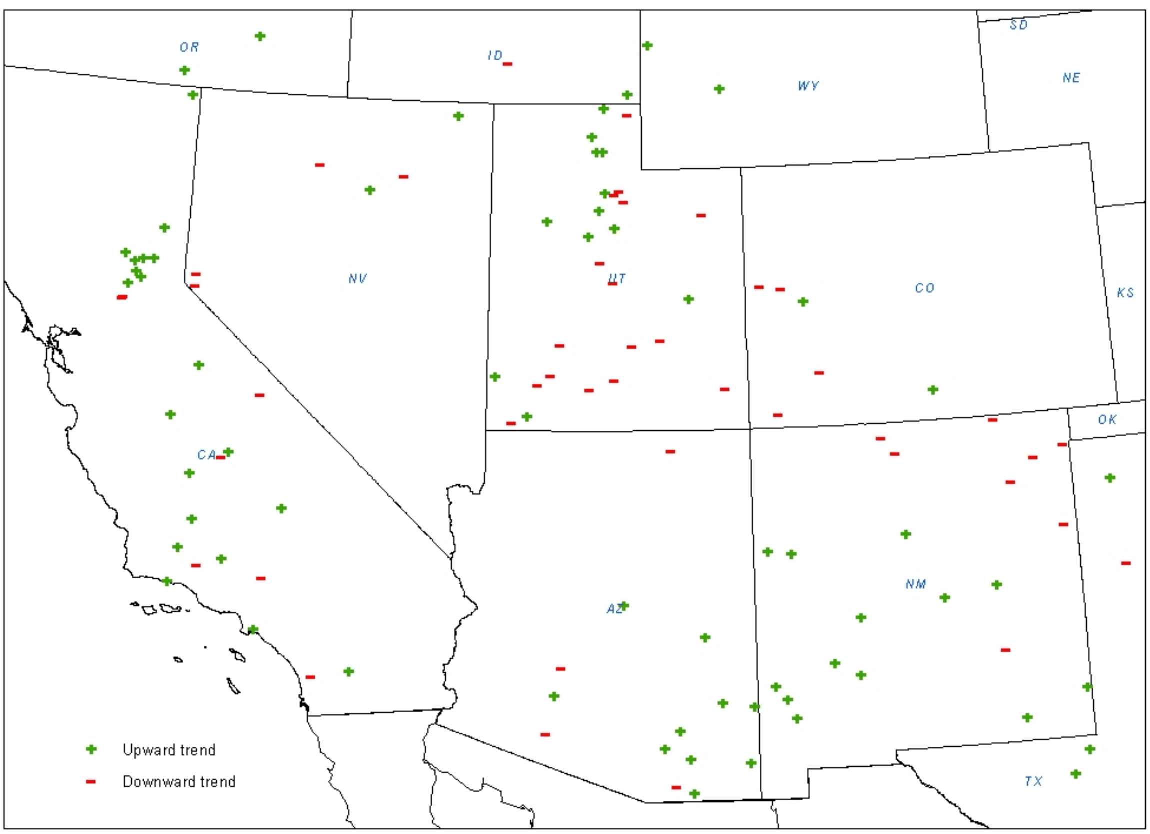
Linear trend tests were conducted to determine if there were any general increasing or decreasing patterns in the 1-day annual maximum series at a station through time. Data were tested for a linear trend in annual maximum series using the linear regression model and t-test (*Handbook of Hydrology*, 1993, p17.30) at the 90% confidence level. Linear trends in variance were also tested. It is necessary for there to be a continuous time series to be eligible for the linear trend test. A minimum length of 50 years was chosen because it is sufficient to give reliable results and is close to the average data length of available stations. 52 stations were not used because they were not continuous (i.e., they had a gap in record of 5 years or longer). The 5-year gap criterion was chosen to maximize the use of limited data while still maintaining the integrity of the time series for the tests.

Linear trend results. Of 1449 stations, 735 (or 50.7%) were eligible for the test. Of those tested stations, **15.2%** exhibited a linear trend in their annual maximum series (9.1% in a positive direction, 6.1% in a negative direction). Table 1 lists the linear trend results by state in the project area. Figure 1 shows the spatial distribution of stations with linear trends.

Table 1. Linear trend test results by state.

State	passed	total trend	pos trend	neg trend	total tested	% stns with trend
Arizona	111	14	10	4	125	11.2
California	192	27	20	7	219	12.3
Colorado	34	6	2	4	40	15.0
Idaho	21	2	1	1	23	8.7
Nevada	34	6	2	4	40	15.0
New Mexico	115	21	13	8	136	15.4
Oklahoma	3	0	0	0	3	0.0
Oregon	5	2	2	0	7	28.6
Texas	24	4	3	1	28	14.3
Utah	79	28	12	16	107	26.2
Wyoming	5	2	2	0	7	28.6
Total	623	112	67	45	735	15.2

Figure 1. Spatial distribution of linear trend results.



Map of stations that have a linear trend in the mean for annual maximum precipitation time series in the 20th century

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Two interesting clusters of upward trending stations are 8 stations in northern California, which may extend through southern California, and a string of 10 stations in northern Utah. These are mountainous areas. There are also numerous upward trending stations in southeast Arizona and south New Mexico, which is an area influenced by monsoonal rain. Negative trending stations seem to be more concentrated centrally in southern Utah southeastward through the northern part of New Mexico.

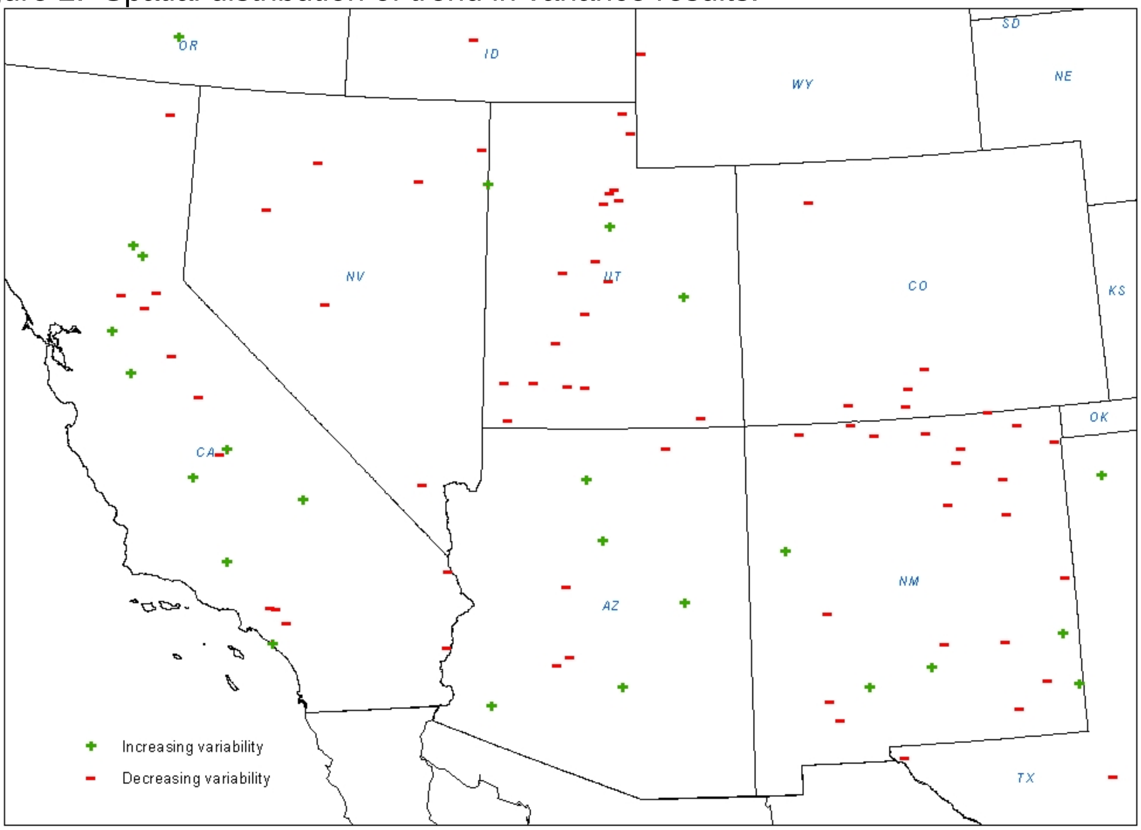
Overall, there appears to be no general linear trend in the tested annual maximum time series and no obvious preference for geographic location.

Linear trend in variance results. Of the 735 stations tested, **12.7%** exhibited a trend in the variance of annual maximums (3.3% in a positive direction, 9.4% in a negative direction). In other words, most stations that exhibited such a trend showed a decrease in variance. Table 2 lists the trend in variance results by state in the project area. Figure 2 shows the spatial distribution of those stations that had a trend in variance.

Table 2. Trend in variance results by state.

State	passed	total trend	pos trend	neg trend	total tested	% stns with trend
Arizona	116	9	5	4	125	7.2
California	198	21	9	12	219	9.6
Colorado	35	5	0	5	40	12.5
Idaho	22	1	0	1	23	4.3
Nevada	34	6	0	6	40	15.0
New Mexico	110	26	5	21	136	19.1
Oklahoma	3	0	0	0	3	0.0
Oregon	6	1	1	0	7	14.3
Texas	25	3	1	2	28	10.7
Utah	87	20	3	17	107	18.7
Wyoming	6	1	0	1	7	14.3
Total	642	93	24	69	735	12.7

Figure 2. Spatial distribution of trend in variance results.



Map of stations that have a linear trend in the variance for annual maximum precipitation time series in the 20th century

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There is an area of negative trend in variance that is roughly consistent with the area of negative linear trend through southern Utah and northern New Mexico.

Overall, there appears to be no general linear trend in variance in the tested annual maximum time series and no obvious preference for geographic location.

Shift Tests

The shift test was conducted to compare the means and variances of 1-day annual maximum series for two consecutive time periods at a station. The data were tested for shifts in mean using Mann Whitney non-parametric test (*Statistics for Business and Economics*, 1988, p403) and the t-test (*Basic Probability and Statistics*, 1980, p160) at the 90% confidence levels. The Mann Whitney is a qualitative test that indicates if a shift occurred but not the direction of the shift. The t-test provides a quantitative measurement of the percentage that the mean shifted from one time period to the next. Both tests give consistent results suggesting that the parametric t-test results can be used with assurance to assign quantitative values to observed shifts. Two dates were used to divide the data into consecutive time periods. First, a division of 1958 was tested because 1958 is the final year for which Technical Paper 40 (Hershfield 1961) had data; second, a division of 1970 was tested because 1970 is the final year of data for NOAA Atlas 2 (Miller et al 1973). The results using these divisions would indicate whether a shift has occurred since the publication of earlier precipitation frequency estimates. A minimum of 30 years of data in each data segment were required at a station to test for shifts in mean. More stations were included using the 1970 split because the dataset has more data in recent years. Only the division of 1958 was used to test for shifts in variance because the test requires more years of data to be statistically meaningful, a minimum of 40 years. The χ^2 test (*Basic Probability and Statistics*, 1980, p162) was used to test for shifts in variance.

Shift in mean results.

The results when using 1958 as the division are:

- t-test: 242 of 1449 (16.7%) were eligible. 14.1% of those tested had a shift in mean (8.7% increased in mean, 5.4% decreased in mean).
- Mann Whitney test: 243 of 1449 (16.8%) were eligible. 15.2% of those tested had a shift in mean.

The results when using 1970 as the division are:

- t-test: 288 of 1449 (19.9%) were eligible. 13.2% of those tested had a shift in mean (7.0% increased in mean, 6.2% decreased in mean).
- Mann Whitney test: 193 of 1449 (13.3%) were eligible. 10.4% of those tested had a shift in mean.

Tables 3 and 4 list the shift in mean results by state in the project area. Table 3 shows the results comparing pre-1958 data and post-1958 data. Table 4 shows the results comparing pre-1970 data and post-1970 data. The last column in each table shows the average percent change in mean for each state. Overall, the shifts in mean show no preference toward increasing or decreasing shifts regardless of what time period is used.

Table 3. Test for shift in mean results (1958 split) by state.

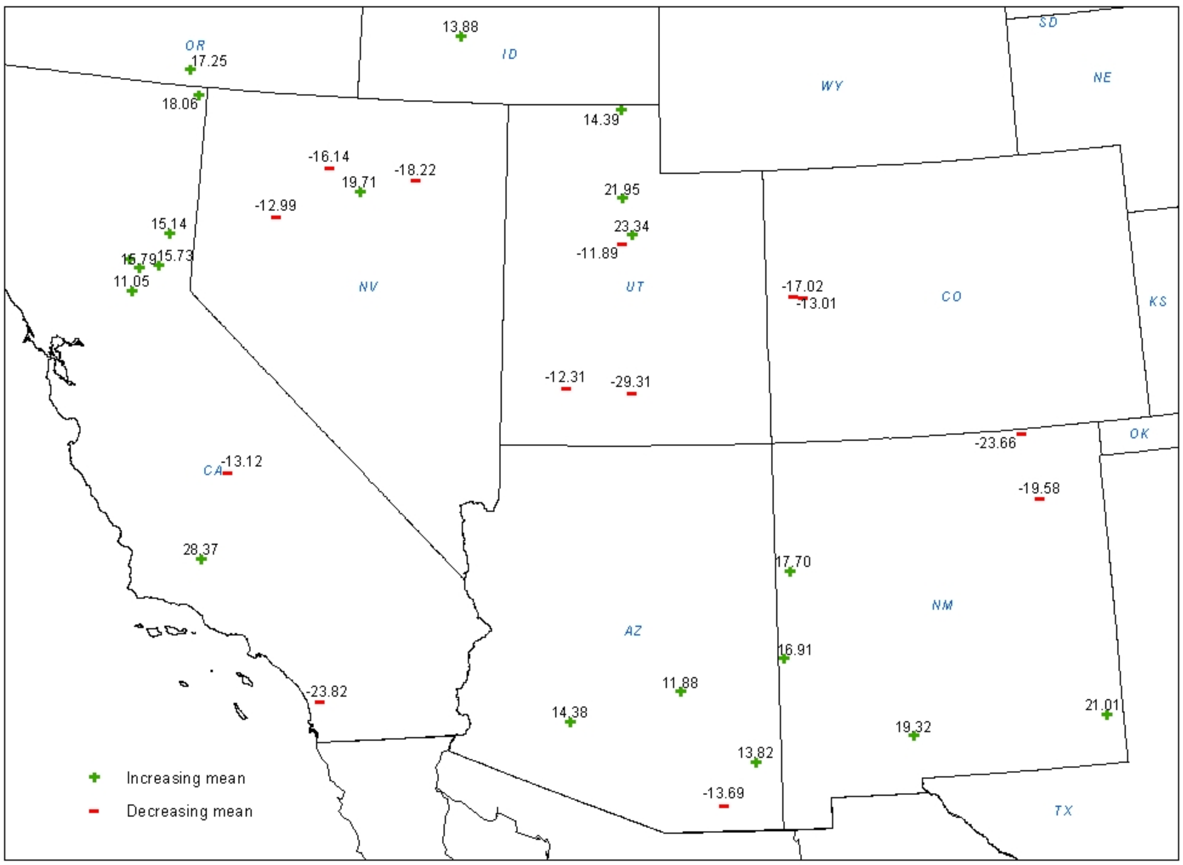
State	passed	total trend	pos trend	neg trend	total tested	% change in mean
Arizona	38	4	3	1	42	6.6
California	50	9	7	2	59	9.3
Colorado	10	2	0	2	12	-15.0
Idaho	9	1	1	0	10	13.9
Nevada	15	4	1	3	19	-6.9
New Mexico	38	6	4	2	44	5.3
Oklahoma	1	0	0	0	1	0
Oregon	0	1	1	0	1	17.3
Texas	2	1	1	0	3	20.1
Utah	41	6	3	3	47	1.0
Wyoming	4	0	0	0	4	0
Total	208	34	21	13	242	4.2 (avg)

Table 4. Test for shift in mean results (1970 split) by state.

State	passed	total trend	pos trend	neg trend	total tested	% change in mean
Arizona	44	5	2	3	49	-4.8
California	70	9	3	6	79	-4.2
Colorado	11	0	0	0	11	0
Idaho	11	1	1	0	12	27.9
Nevada	14	5	2	3	19	-8.3
New Mexico	45	8	6	2	53	9.7
Oklahoma	1	0	0	0	1	0
Oregon	3	0	0	0	3	0
Texas	11	1	1	0	12	25.0
Utah	40	9	5	4	49	1.3
Wyoming	0	0	0	0	0	0
Total	250	38	20	18	288	1.0 (avg)

Figures 3 and 4 show the spatial distribution of the stations that have a shift in mean. The numbers by the station location indicate the percentage of change in mean at each station. Clusters of upward shifting means in northern California (Figure 3) and in northern Utah (Figures 3 and 4) are consistent with the linear trend results. However, given the sparsity of stations tested, it is difficult to draw any conclusions.

Figure 3. Spatial distribution of shift in mean results, where the number indicates the percentage of change (1958 split).



Map of stations that have a shift in the mean for annual maximum precipitation time series in the 20th century (1958)

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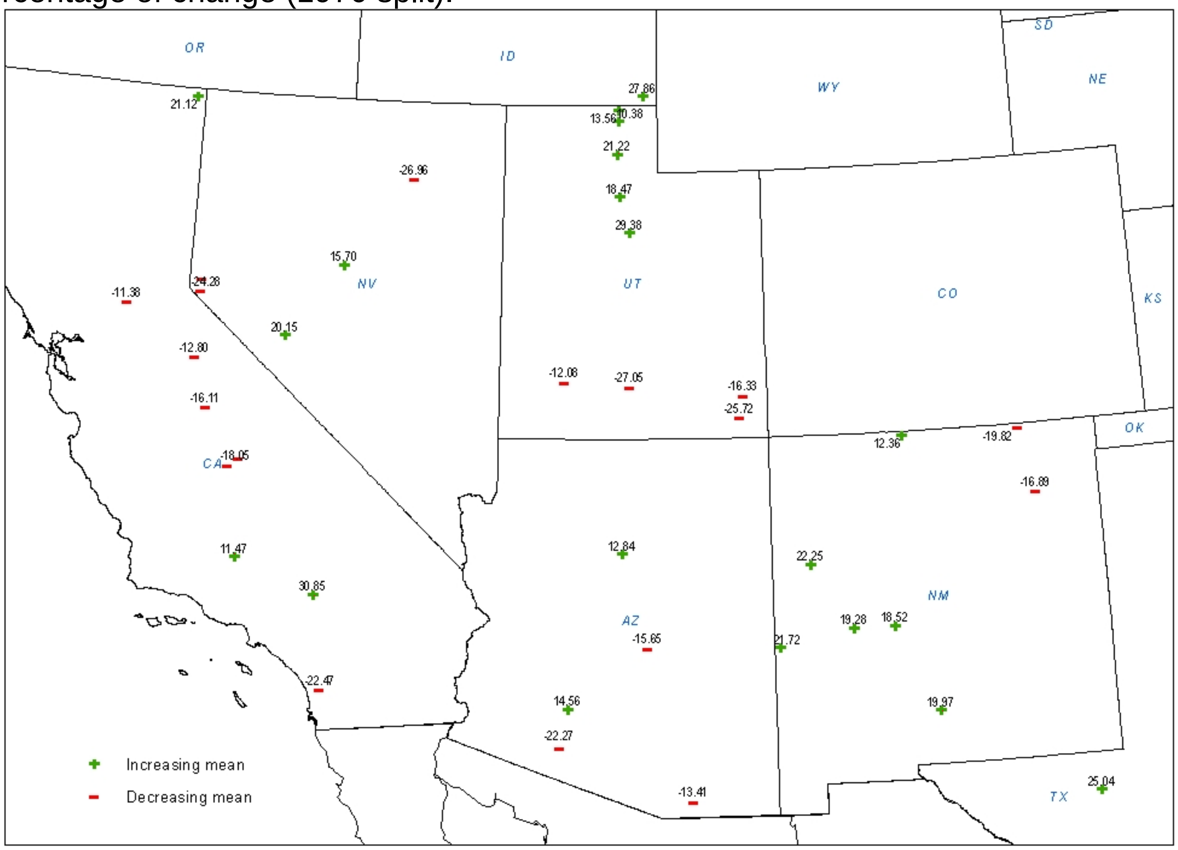
Figure 4. Spatial distribution of shift in mean results, where the number indicates the percentage of change (1970 split).



Map of stations that have a shift in the mean for annual maximum precipitation time series in the 20th century (1970)

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Shift in variance results. The results for the χ^2 test for shift in variance are that 199 of 1449 (13.7%) were eligible. Of those tested, 55.8% had a shift in variance. The results for the shift in variance are similar to the Ohio River Basin and Surrounding States Precipitation Frequency Project (Lin and Julian, 2001), in which 55% of the stations tested demonstrated a shift in variance. However, unlike the Ohio project, which showed a regional average increase of 23% in the standard deviation, the Semiarid project showed a regional decrease of -5.6%. This overall decrease is consistent with the trend analysis that showed more decreasing trends in variance than increasing.

Specific Examples

In many cases, stations that showed a linear increase or decrease had a similar shift in mean. Figure 5 shows a combined upward linear trend with an upward shift in mean (1958 split) at Dobbins 1 S, CA. These data passed the randomness test and can be considered independent. The time series for the station (1904 - 2000) is plotted with a solid straight line representing the linear trend. There was an accompanying increasing shift in mean (+16.6%) from the1904 -1958 time period (3.01") to the 1959-2000 time period (3.51"). The means of each time period are represented as separate horizontal lines. There were not enough data in the latter part of the record for this station to be tested for a shift in mean with the 1971 split. This station did not exhibit a linear trend in the variance of the mean. This station did not have enough data to meet the data length requirement for the shift in variance test.

Figure 5. Plot of increasing linear trend and shift (split 1958) tests for annual maximum time series at Dobbins 1 S, CA.

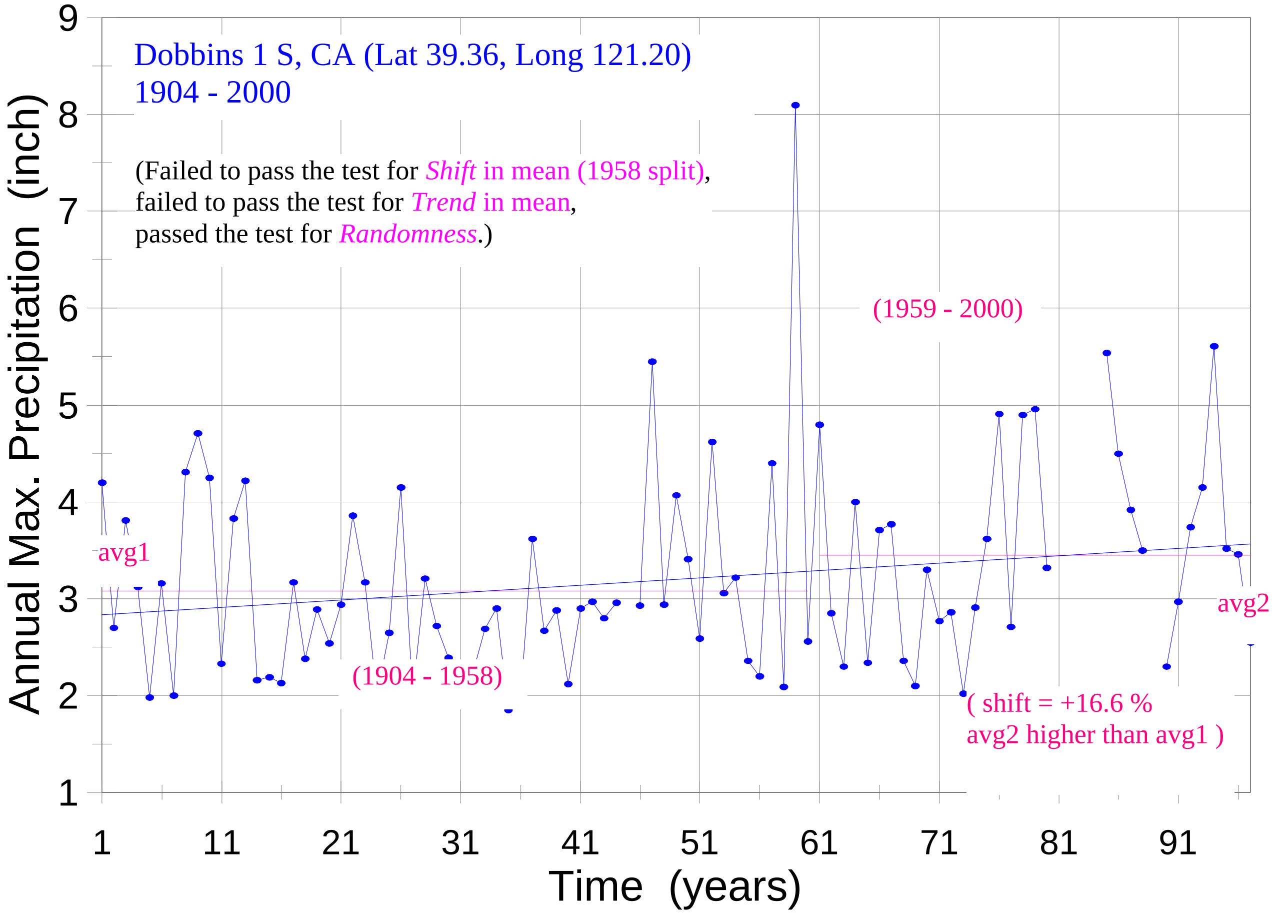
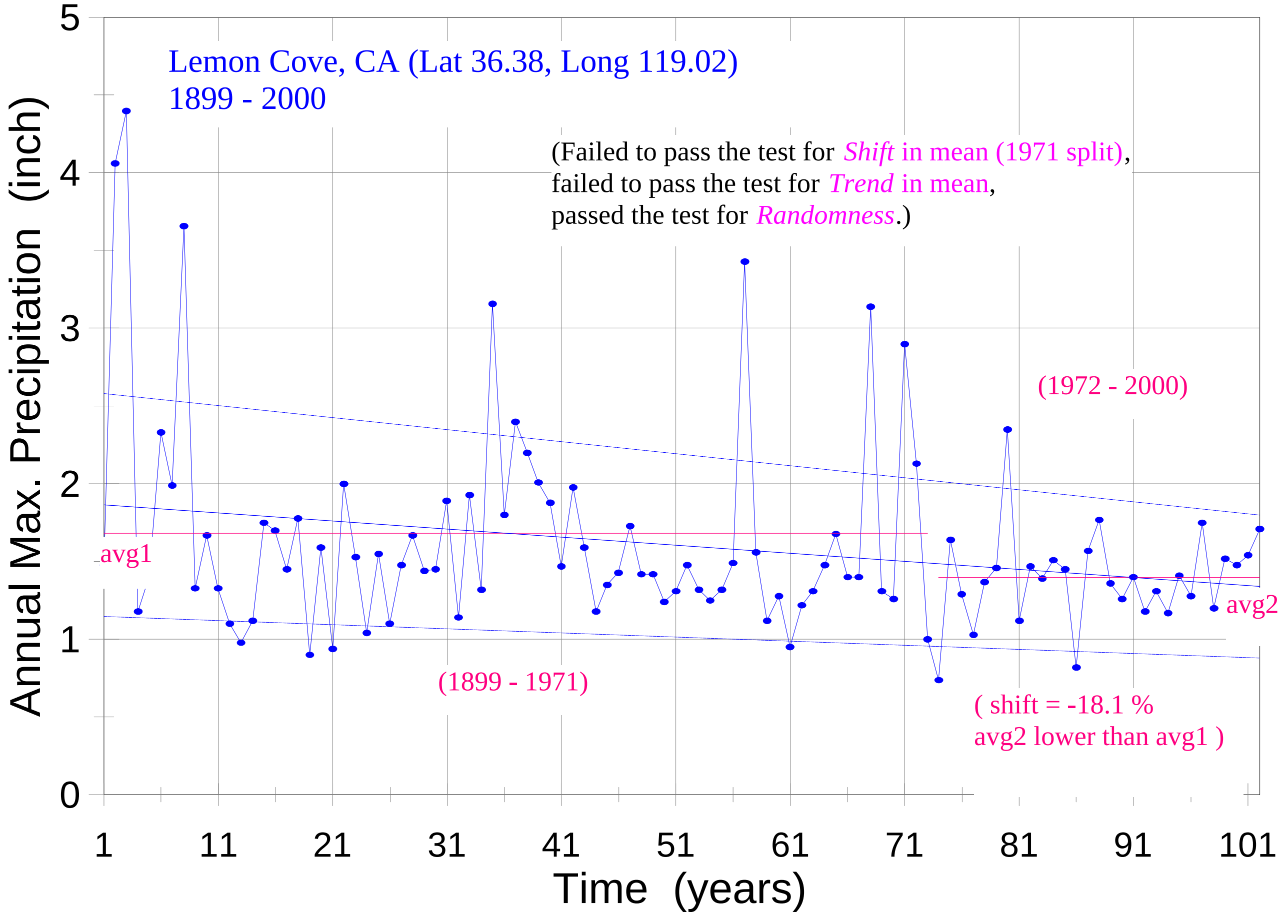


Figure 6 shows a combined downward linear trend with a downward shift in mean (1971 split) at Lemon Cove, CA. The data record, 1899 - 2000, provided enough data to run all tests. These data passed the randomness test. A decreasing linear trend and a decreasing shift in mean for both the 1958 and 1971 splits were observed. The 1899-1958 mean, 1.69", decreased by 13.1% to 1.47" in 1959-2000. The 1971 split showed that the 1899-1971 mean, 1.69", decreased by 18.1% to 1.39" in 1972-2000, as depicted in the Figure. The linear trend in variance and shift in variance were also decreasing through time. This means that there were less extreme events with time. The decrease in variance is shown in the Figure by the dashed lines outward of the linear trend line.

Figure 6. Plot of decreasing linear trend and shift (split 1971) tests and decreasing linear variance for annual maximum time series at Lemon Cove, CA.



Conclusions

1-day precipitation annual maximum series for stations in the Semiarid Southwestern United States were examined for randomness, linear trends, linear trends in variance, and shifts in mean. The following conclusions about the stations tested can be made:

1. The annual maximum precipitation time series data used in the Semiarid project are random and independent.
2. Overall, the annual maximum time series are free from linear trends and from shifts in mean for most of the stations in the Semiarid project area.
3. Aside from 2 clusters, there appears to be no definite preference in geographical location for stations exhibiting trends or shifts for those stations tested.

Therefore, it was assumed that long-term effects of climate change are negligible for the precipitation frequency analyses in NOAA Atlas 14.

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